GANIL Operation Status and New Range of Post-Accelerated Exotic Beams

O. Kamalou, J. Angot, O. Bajeat, F. Chautard, P. Delahaye, M. Dubois, T. Lamy, L. Maunoury, G. Normand, A. Savalle

GANIL OPERATION STATUS AND NEW RANGE OF POST-ACCELERATED EXOTIC BEAMS

O. Kamalou[1)], J. Angot[2)], O. Bajeat[1)], F. Chautard[1)], P. Delahaye[1)], M. Dubois[1)], T. Lamy[2)], L. Maunoury[1)], G. Normand[1)], A. Savalle[1)]
1) GANIL, Grand Accélérateur National d'Ions Lourds, CEA-DSM/CNRS-IN2P3, Bvd H. Becquerel, BP 55027 14076 Caen cedex 5, France
2) LPSC - Université Grenoble Alpes - CNRS/IN2P3, 53 rue des Martyrs, F-38026 Grenoble cedex, France

Abstract

The GANIL facility (Grand Accélérateur National d'Ions Lourds) at Caen produces and accelerates stable ion beams since 1982 for nuclear physics, atomic physics, radiobiology and material irradiation. The range of stable beam intensity available at GANIL extends from very low intensity (< 109 pps) to high beam intensity (~2.1013 pps). The review of the operation from 2001 to 2015 is presented. One of the methods to produce exotic beam at GANIL, is the Isotope Separation On-Line method with SPIRAL1 facility. It is running since 2001, producing and post-accelerating radioactive ion beams mainly from gaseous elements. Due to the physicists demands for new radioactive nuclei, the facility is being improved in the framework of the project "Upgrade SPIRAL1". The goal of the project is to extend the mass range of post-accelerated as well as low energy exotic beams using devoted 1+ Target Ion Source System associated with a charge breeder. The latest results of the charge breeder tests and the status of the upgrade will be presented.

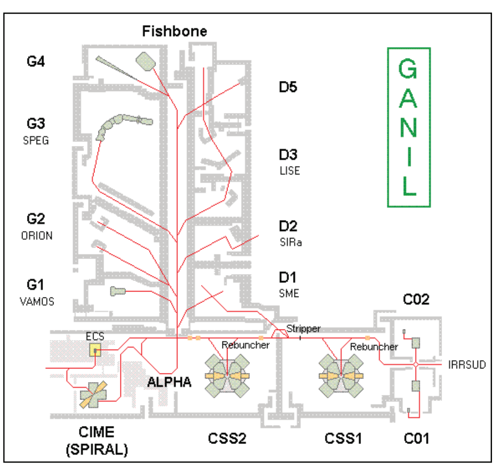

Figure 1: GANIL layout.

OPERATION REVIEW

Multi-beam delivery is routinely done at GANIL using its 5 existing cyclotrons. Up to five experiments can be run simultaneously in different rooms with stable beams (Fig. 1):

1. Beams from C01 or C02 are sent to an irradiation beam line IRRSUD (<1MeV/u).
2. A charge state of the ion distribution after the ion stripping foil downstream CSS1 is sent to atomic physics, biology and solid states physics line D1 (4-13MeV/u).
3. A high-energy beam out of CSS2 is transported to experimental areas (<95MeV/u), for nuclear physics and previous applications.
4. An auxiliary experiments may share the previous CSS2 beam (10% of the pilot experiment time)
5. Finally, stable beams from SPIRAL1 source can be sent to LIRAT (<10 keV/q) or post-accelerated by CIME and used for testing detector for example.

During radioactive beam production with SPIRAL1, the combinations are reduced to the four first (cases 1, 2, 3, 4) and radioactive beam is sent to the experimental areas.

2001-2015 GANIL OPERATION STATUS

Since 2001 (Fig. 2), more than 71400 hours of beam time has been delivered by GANIL to physics, which correspond to 88.6 % of scheduled experiments.

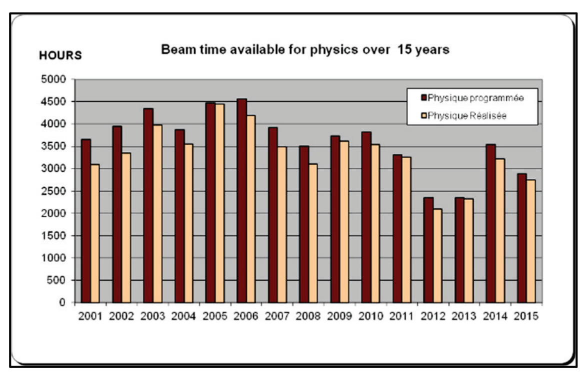

Figure 2: Beam time available for physics over 15 years.

In average, the number of beams delivered per year has increased until 2010. Owing to the construction and assembly of the new SPIRAL2 accelerator, the running time has been shrinked to devote more human ressources to the project, in particulier in 2012 and 2013 with only 2000 hours of running time (instead of 3500 hours per years).

Figure 3 shows the statistic running of the machine over 14 years. As we can see, 67 % of beam time is dedicated to Physics and 12.5% for machine tuning.

ISBN 978-3-95450-131-1

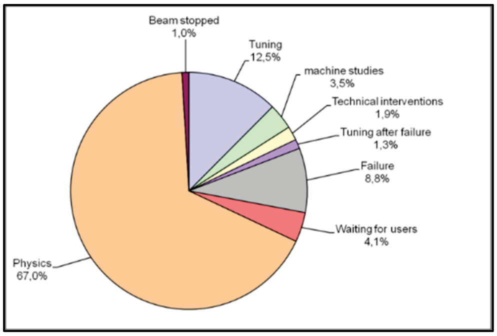

Figure 3: Statistic running of the machine between 2001 and 2015.

SPIRAL1 UPGRADE

The first Isotope Separator On Line System installed at GANIL, named SPIRAL1, has delivered radioactive ions for 13 years. Radioactive atoms produced by fragmentation of swift heavy ions (up to 95 MeV/u) on a carbon target are ionized in an ECR multi-charged ion source before being post-accelerated in a cyclotron. Due to the design of the target ion source system (TISS), mainly gaseous ions are produced. To satisfy the request of physics community for extending the choice of ions to those made from condensable elements, with masses up to Xe, an upgrade of SPIRAL1 has been undertaken [1]. Beams and technical options considered during the prospective phase have been sorted out. A schematic of the ongoing upgrade is presented in Fig. 4. Surface ionization, FEBIAD (Forced Electron Beam Induced Arc Discharge) or ECR (Electron Cyclotron Resonance) ion sources [2, 3] will be installed in the production cave after its modification to provide 1+ beam of condensable elements. Out of the cave and after mass separation, a Phoenix charge breeder will be installed on the present low energy beam line to increase the charge of the radioactive ions from 1+ to N+ for post-acceleration to get energy up to 25 MeV/A using CIME accelerator [4].

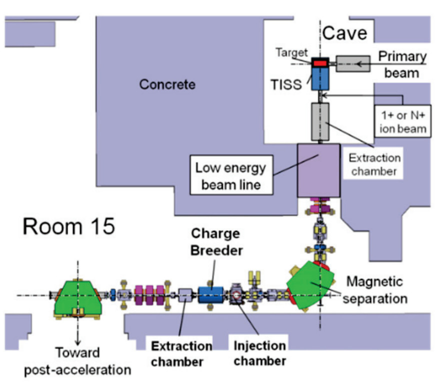

Figure 4: Schematic of the SPIRAL1 upgrade.

NEW BEAMS VERSUS NEW TISS

New elements will be mainly produced by fragmentation of the primary beam ions on a graphite target. Thus most of the masses and atomic numbers will generally not be higher than those of the primary beams available at GANIL. The elements to be produced can be divided in three groups:

1- Alkali elements and alkaline earth elements (Li, Mg, Na, Al, Ca, K, Rb and Sr). The elements could be ionized in an existing TISS, already tested and optimized on line at GANIL on a test bench.

2- Metallic ions (Sc, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ge, As and Se). They will be produced by association of a carbon target with a FEBIAD of VADIS (Versatile Arc Discharge Ion Source) type developed at CERN (Fig. 5). This association indicates good performances for the TISS and yields have been measured favorably for Mg, Al, Cl, K, Mn, Cu and even Fe ions [5].

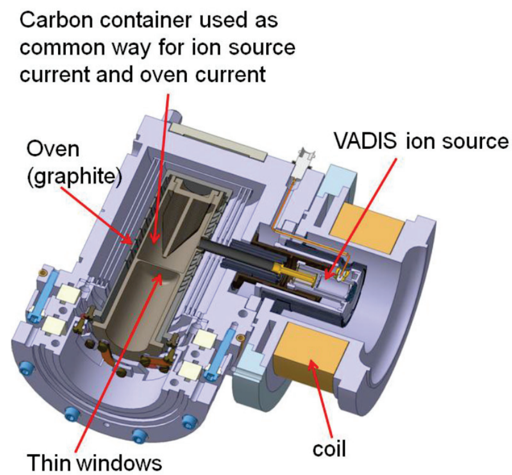

Figure 5: TISS made by association of a graphite target with a VADIS FEBIAD ion source.

3- Non-metallic ions, halogen and rare gas ions (He, Ne, Ar, Kr, O, C, P, Cl and Br). Multi-charged ions from rare gases, C and O are currently produced using the ECR ion source of SPIRAL1 upgraded to enhance the ionization efficiencies.

Because of the length of the singly-charged ion sources is shorter than the present NANOGAN III ECRIS along the low energy beam line axis, a chamber containing optical elements will be installed to transport and adapt the 1+ beam to charge breeder.

CHARGE BREEDER MODIFICATION

Figure 4 shows the connection of the charge breeder in the beam line. Generally, a double Einzel lens is used to focus the 1+ beam into a charge breeder, in order to give more flexibility on the optical tuning, it has been replaced by an electrostatic quadrupole triplet. A movable puller and Einzel lens are mounted in the extraction box; the puller is made of stainless steel. The charge breeder is based on the Phoenix Booster developed at LPSC Grenoble and used at ISOLDE to determine its characteristics with radioactive

ISBN 978-3-95450-131-1

ions [6]. The major features have been described in the reference [7].

EXPERIMENTAL RESULTS

The following procedure was done before each optimization – measurement of charge breeding efficiency or time. Charge breeder OFF (RF OFF), the 1+ incoming is maximized on the faraday cup located (FC1+) before the quadrupole triplet and on the faraday cup (FCn+) placed downstream the charge breeder after the mass over charge separation provided by a 120° dipole. Thereafter, charge breeder ON (RF ON), the charge breeder is tuned so as to get the highest <Z> possible for the buffer gaz charge state distribution (CSD). The charge breeding efficiency and time are measured by pulsing the incoming 1+ beam using and electrostatic steerer and measuring the n+ response on FCn+. The n+ signal is maximized thanks to all available parameters of the charge breeder (RF power, magnetic field, buffer gas) as those of the beam line (voltages on Einzel lenses, voltages on the quadrupole triplet electrodes, position of deceleration grounded tube, etc…). The acceleration voltage of the 1+ ion beam was set at 20 kV, the charge breeder voltage being accurately tunable around this value (20 kV± ΔV. The RF power was always around 350 - 400W and the total current from high voltage supply was in the range 0.5 – 0.8 mA.

The charge breeder had to be tested with condensable elements: alkali elements which are easy to ionize using pellets from the HeatWaveLabs [8] have been chosen for this purpose. Na^{1+}, K^{1+} and Rb^{1+} beams were successively produced and injected into the charge breeder; typical intensities were in the range from 200 to 400 nA. Charge state distributions obtained by the breeding process in different situations are presented in the Figure 6.

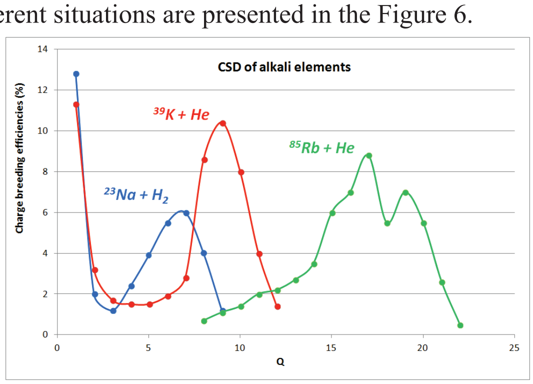

Figure 6: Charge state distributions of alkali elements with He or H2 as buffer gas.

Focused on the ^{39}K case, the Figure 7 displays a graph on the evolution of the ^{39}K CSD with the buffer gas. Lighter is the buffer gas, higher is the charge breeding efficiency of the $^{39}K^{9+}$ and narrower is the CSD. It is an important parameter for the future accelerated beams after CIME. Increasing the charge Q of the ion proportionally increases the final energy. In the case of a $^{39}K^{10+}$ beam, the buffer gas should be He contrary to $^{39}K^{9+}$ where it should be H_2. The effects of the ΔV value and of the buffer gas on the charge breeding process are described in much more details in [9].

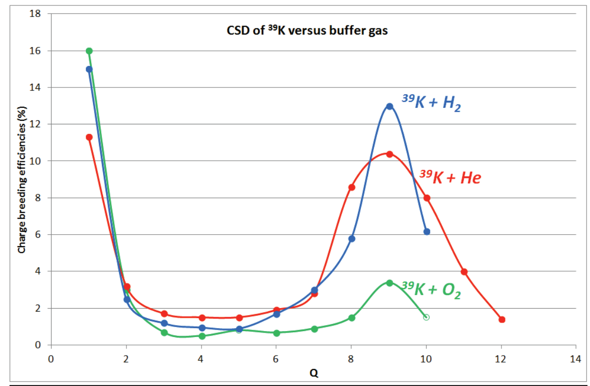

Figure 7: Evolution of the Kn+ charge state distributions versus buffer gas.

REFERENCES

[1] P. Jardin et al., Rev. Sci. Instrum. 83, 02A911(2012)
[2] S. Sundell et al., Nucl. Instrum. Method. B 70 (1992) 160-164.
[3] R. Vondrasek et al., Rev. Sci. Instrum. 83, 02A913(2012)
[4] C. Tamburella. Thesis, ISN Grenoble (1996).
[5] O. Bajeat et al., Nucl. Instr and Meth. in Phys. Res (2013)
[6] P. Delahaye et al, Review of Scientific Instruments. 77, 03B105 (2006)
[7] P. Delahaye et al., Nuclear Instruments and Methods in Physics Research A. 693, 104 (2012)
[8] T. Lamy et al., Proceedings of the 21st International Workshop on ECR Ion Sources, Nizhny Novgorod, Russia, 24th -28th August 2014
[9] L. Maunoury et al., submitted to Rev. sci. Instr. For publication in the proceedings of the 16th International Conference on Ion Sources, New-York, August 23-28, 2015.

ISBN 978-3-95450-131-1